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ABSTRACT

In 2003 the author attended the AEW&C Operational Mission System (OMS) simulator preliminary design review. The design for the Distributed Interactive Simulation (DIS) interface on this simulator was not well developed and a significant amount of work was required to bring the AEW&C OMS simulator's DIS interface up to a suitable standard to provide a useful level of interoperability. This report documents the processes used to develop a minimum, basic set of DIS message packets (Protocol Data Units (PDUs)) that should provide sufficient interoperability to enable the (or any other ADF) simulator to participate in a DIS, Wide Area Network, training exercise at the time the simulator is accepted by the ADF without expensive after acceptance modification.

Although used for the AEW&C OMS simulator the recommended, base, minimum set of DIS PDUs is not directed at any particular platform or project and is meant to be the generic starting point for any ADF simulator DIS interface. An analysis of platform specific functionality would also be required to provide additional platform specific DIS PDUs.

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Executive Summary

In 2003 the author attended the AEW&C Operational Mission System (OMS) simulator preliminary design review. The Distributed Interactive Simulation (DIS) interface on this simulator was not well developed and a significant amount of work was required to bring the AEW&C OMS simulator's DIS interface up to a suitable standard to provide a useful level of interoperability.

This report documents the processes used to provide a minimum, basic set of DIS message packets (Protocol Data Units (PDUs)) that should provide sufficient interoperability to enable this (or any other Australian Defence Force (ADF)) simulator to participate in a DIS, Wide Area Network, training exercise at the time the simulator is accepted by the ADF without expensive after acceptance modification.

Although used for the AEW&C OMS simulator the recommended, base, minimum set of DIS PDUs is not directed at any particular platform or project and is meant to be the generic starting point for any ADF simulator DIS interface. An analysis of platform specific functionality would also be required to provide additional platform specific DIS PDUs.

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Dr Lucien Zalcman graduated from Melbourne University with a BSc (Hons.) in 1973. He was awarded a PhD in Physics from Melbourne University in 1980. He also completed a Graduate Diploma in Computing Studies at RMIT graduating in 1987. During the period 1980 - 1984 he worked as an Experimental Officer at the CSIRO Division of Mineral Chemistry carrying out research into lead acid batteries for electric vehicles. He joined DSTO in 1984 as an Information Technology Officer in the Computer Centre at the Aeronautical Research Laboratory. In 1992 he was employed as a Senior Professional Officer in Air Operations Division of AMRL specialising in the field of Distributed Interactive Simulation. He was promoted to Senior Research Scientist in 1998.

Contents

Glossary of Abbreviations and Acronyms

ACSS	Air Command Support System
ADF	Australian Defence Force
ADGESIM	Air Defence Ground Environment Simulator
ADS	Advanced Distributed Simulation
AEW&C	Airborne Early Warning & Control
AFS	Advanced Flight Simulator
API	Application Programmers Interface
ARPA	Advanced Research Projects Agency
ASE	Army Synthetic Environment
ATC	Air Traffic Control
BFTT	Battle Force Tactical Training
BMEE	BFTT Multiphase Electromagnetic Emission
BOPC	Battle Force Tactical Training Operator Processor Console
BSEE	BFTT Supplemental Electromagnetic Emission
CGF	Computer Generated Forces
COTS	Commercial-Off-The-Shelf
CReaMS	Coalition Readiness Management System
CSTT	Combat System Tactical Trainer
DAC	DSI Communications System
DDG	Guided Missile Destroyer
DIS	Distributed Interactive Simulation
DMO	Distributed Mission Operations
DMSO	Defense Modeling and Simulation Office (US)
DMT	Distributed Mission Training
DSTO	Defence Science and Technology Organisation
ECP	Engineering Change Proposal
EMC	Exercise Management Console
ESPDU	Entity State Protocol Data Unit
FOM	Federation Object Model
FFG	Guided Missile Frigate
HIL	Human-In-The-Loop
HLA	Higher Level Architecture
I/ITSEC	Interservice / Industry Training, Simulation and Education Conference
ID	Identification
IEEE	Institute of Electrical and Electronic Engineers
IFF	Identify friend or Foe
IOTTF	Integrated Operations Team Training Facility
ISDN	Integrated Services Digital Network
ITC	Interim Training Capability
JOANNE	Joint Air Navy Networking Environment
JORN	Jindalee Operational Radar Network
JSF	Joint Strike Fighter
LBTS	Land Based Test System
MWTC	Maritime Warfare Training Centre
MWTS	Maritime Warfare Training System
NATO	North Atlantic Treaty Organisation
NAVAIDS	Navigational Aid Systems
NAWTSD	Naval Air Warfare Center Training Systems Division
NTFM	(US) Naval Training Meta-FOM
OBTS	On Board Training System
OMS	Operational Mission Simulator
PDU	Protocol Data Unit

RAAF	Royal Australian Air Force
RAN	Royal Australian Navy
RPR-FOM	Real-time Reference Federation Object Model
RTI	Run Time Infrastructure
SIMNET	Simulator Networking
SIMPLE	Standard Interface for Multiple Link Evaluation
SM	Simulation Manager
SMOC	Simulation Middleware Object Classes
SOM	Simulation Object Model
SISO	Simulation Interoperability Standards Organisation
STANAG	Standard NATO Agreement
TADIL	Tactical Digital Information Link
TT	Tactical Trainer
UA	Underwater Acoustic
USN	United States Navy
VAE	Virtual Air Environment
WAN	Wide Area Network

1. Introduction

Over the next decade the Australian Defence Force (ADF) will continue to develop and acquire platform training simulators for air, maritime and land assets. Many of these simulators will have the capability of being networked together using Advanced Distributed Simulation (ADS). The adoption of such ADS technologies will enable increased and enhanced training capabilities and opportunities at reduced costs [1, 2].

Existing network-enabled training simulators include the Royal Australian Navy's (RAN) Integrated Operations Team Training Facility (IOTTF) FFG ship and Combat System Tactical Trainer (CSTT) Anzac ship simulators located at the Maritime Warfare Training Centre (MWTC) [3, 4, 5] at HMAS Watson, the Royal Australian Air Force's (RAAF) AP-3C simulator [6, 7] located at RAAF Edinburgh and the RAAF DSTO developed Air Defence Ground Environment SIMulator (ADGESIM) [8, 9] used operationally at RAAF Williamtown and RAAF Darwin. Other platform simulators, which may be networked in the future, include the Seasprite, Seahawk, and Armed Reconnaissance Helicopter simulators, the Collins submarine simulator, the FFG UP simulator [10] and the Airborne Early Warning & Control (AEW&C) Operational Mission System simulator [11, 12]. Section 2 gives an overview of Distributed Simulation in the ADF.

In 2003 the author attended the AEW&C Operational Mission System simulator preliminary design review (PDR) [13]. The Distributed Interactive Simulation (DIS) interface on this simulator was insufficiently developed and a significant amount of work was required to provide the project with advice on what protocols were required to bring the simulator's ADS interface to a suitable and useful standard.

This report documents the processes used to provide a minimum, basic set of DIS Protocol Data Units (PDUs) that could be implemented by any ADF DIS simulator. This basic set of DIS PDUs should provide sufficient, application protocol interoperability to enable the simulator to participate in a DIS, Wide Area Network, training exercise at the time the simulator is accepted by the Commonwealth (ie without expensive after acceptance modification).

There may be several ways to determine what DIS Protocol Data Units (PDUs) should be used in a platform simulator to achieve the required application protocol interoperability. Two such processes are used in section 6 to produce the recommended, minimum, starting set of DIS PDUs required for any ADF DIS simulator.

Although used for the AEW&C Operational Mission System simulator project, the recommended, minimum, basic set of DIS Protocol Data Units (PDUs) is not directed at any particular platform or project and thus a set of platform specific capabilities is not required for analysis. The approach used in this report is to use the author's experience

with particular ADF DIS simulator projects (RAN HMAS Watson IOTTF and CSTT, RAN FFG UP, RAAF AP-3C OMS, RAAF AEW&C OMS, and RAAF ADGESIM simulators) to discuss and compare the commonly used DIS PDUs in such simulators. This methodology should give a basic set of DIS PDUs required to provide an acceptable level of application protocol interoperability.

In addition, the functions specifically carried out by the platform to be simulated would also need to be analysed. The additional DIS PDUs required to specifically support distributed training of this particular platform's capabilities can then be determined [3]. For example if the platform being simulated is required to search for submarines the platform simulator will most likely need to support the Underwater Acoustics PDU. An F/A-18 aircraft is unlikely to have such a capability and therefore an F/A-18 simulator would not be required to support this PDU.

The author is also involved in the development of the RAAF Virtual Air Environment (VAE) ADGESIM simulator [8, 9] and the results of this report will be used to upgrade the DIS interface of the ADGESIM simulator to attain the recommended level of interoperability.

To familiarise the reader with DIS a general discussion of DIS is given in section 3 - *What Is DIS?*

2. Advanced Distributed Simulation in Australia

Significant technology demonstrations in Australia have shown the value of distributed simulation, and have contributed to the planned delivery of simulation systems to the ADF.

2.1 The VAE Demonstrations

Four VAE demonstrations [14-18] have demonstrated: interoperability between Human-In-The-Loop and Computer Generated Forces simulators from different services using DIS; the use of computer controlled artificial agents as enemy forces; the capability to fuse and correlate data from and into dissimilar, real sensor systems; and the use of DIS voice communications all connected on a geographically dispersed Wide Area Network (WAN).

2.2 The SimTecT2002 Synthetic Environment Demonstration

DIS and Higher Level Architecture (HLA) simulators from the Australian Army, Navy and Air Force interoperated in the SimTecT2002 demonstration. A USN system (Battle Force Tactical Training Operator Processor Console - BOPC) also participated. Defence and Industry resources combined to showcase this demonstration. Current operational and future (Armed Reconnaissance Helicopter, Global Hawk and Wedgetail AEW&C

aircraft) capabilities participated, highlighting the training, research and acquisition potential of a synthetic environment.

2.3 The Australian / US Navy Distributed Simulation Coalition Training Exercises

The US Navy's Battle Force Tactical Training (BFTT) Program provides on-board training using DIS to naval fleet units. This technology enables a number of ships and shore units to participate in the same virtual battlespace even though they may be geographically dispersed.

Australia and the United States are collaborating in the area of simulation for training via both a RAN/USN Heads of Agreement and a DSTO/USN Project Arrangement. This collaboration will ultimately ensure that Australian Navy training systems both in the ships and ashore will be able to interoperate with their USN counterparts. The RAN would then be able to participate in virtual coalition training exercises with the USN without needing to send ships and crews to designated exercise areas [11].

The main objective of these coalition, training exercises is to enhance warfighting readiness through the development of a coalition team training and combined mission rehearsal capability [11, 19, 20]. The first such exercise joined operational team training simulators at HMAS Watson with USN training simulators at Dam Neck, Virginia and the I/ITSEC 2001 Conference floor at Orlando, Florida. The Netherlands Navy also participated from the TNO in the Netherlands. DSTO provided technical assistance and analysis of the data from this unclassified exercise.

Connectivity between these locations was established using commercial ISDN WAN service providers (eg Telstra in Australia). DIS Entity and DIS radio communication interoperability was achieved. Video conferencing was provided to assist both the set up and the After Action Review processes. Learning methodology research was also carried out during this exercise [8, 21].

The next exercise, in February 2003, built on knowledge and experience gained from the I/ITSEC 2001 exercise. The February 2003 exercise was classified and also implemented a TADIL Link 11 capability. Classified WAN exercises introduce security and encryption issues. Lessons learned from this February 2003 training exercise will most likely benefit all future ADF distributed simulation exercises.

On completion of this exercise, coupled with all the other demonstrations and exercises already carried out in Australia, many of the relevant distributed simulation technologies required during a typical classified, joint, coalition, WAN training exercise will have been researched, evaluated and installed.

Because the USN/RAN simulators (ie. BFTT/FFG Upgrade) used in these exercises will be the same as the real on-board training systems, the laboratory to laboratory and

shore trainer to shore trainer exercises could now start the shift to ship to ship training. This will enable coalition mission rehearsal on operational platforms - train as we (ie where we) fight [19].

2.4 The DSTO JOint Air Navy Networking Environment Project (JOANNE)

DSTO's Air Operations Division has initiated development of the JOANNE [1, 2, 19-22] Project. JOANNE will provide the ADF with the technical architecture for a synthetic environment for training using existing simulation facilities. It will benefit various existing sponsored projects including SEA 1412 and the VAE, and, through multinational defence agreements, seek to facilitate collaboration with the US Navy's Battle Force Tactical Training (BFTT) Program and the US Air Force's Distributed Mission Training (DMT - recently renamed Distributed Mission Operations (DMO)) Program.

2.5 The RAAF VAE Project and the RAN Project SEA 1412

Both the RAAF VAE and RAN SEA 1412 Projects have historically followed similar trends.

Because of the planned introduction of new Air Defence / Fighter Control systems (Jindalee Operational Radar Network (JORN), Airborne Early Warning and Control (AEW&C) and the Air Command Support System (ACSS)) and the corresponding increase in Flight Controllers, live asset training opportunities per Flight Controller will diminish significantly. The VAE Project was originally intended to alleviate these Flight Controller training deficiencies [23]. An Interim Training Capability (ITC) simulator was planned to be delivered by industry as part of the VAE. However, because of significant changes to the scope and the scale of the required capability, as part of VAE phase 2, DSTO has delivered its Air Defence Ground Environment Simulator (ADGESIM) to RAAF Williamtown in place of the ITC.

Initially SEA 1412 was developed to add DIS interfaces to the Anzac and FFG/DDG simulators at HMAS Watson to share simulator resources to enhance command team training and tactical development [3-5]. The addition of a Wide Area Network (WAN) capability at HMAS Watson and the signing of a US Navy and DSTO/RAN Project Arrangement has resulted in a series of exercises intended to enhance warfighting readiness through the development of a combined coalition team training and mission rehearsal capability [22].

DSTO views these Projects (under JOANNE) as the ADF joint component, virtual environments on which research and development, evaluation and deployment of research and operational, distributed simulation systems takes place. All such systems should (where practical and applicable) comply with the appropriate DSTO JOANNE standards to ensure the maximum probability of interoperability and scalability [11].

2.6 Maritime Warfare Training System

Through Project SEA 1412, the RAN is developing the Maritime Warfare Training System (MWTS) which initially links several existing surface warfare trainers to provide enhanced command team and tactical training for the RAN into the future.

In later phases of the Project, an Australian wide-area maritime simulation network will be established. This system could include ships alongside at the Fleet Bases, linked via their on-board training systems with the wargaming system and ship models at HMAS Watson in Sydney, as well as other ADF simulators, such as RAN helicopter simulators, RAAF AP-3C, F/A-18 and AEW&C aircraft simulators [5, 11-12].

2.7 FFG On Board Training Systems

In parallel with development of SEA 1412, the RAN's Guided Missile Frigates (FFGs) are acquiring Distributed Interactive Simulation (DIS) compatible On Board Training Systems (OBTS) under Project SEA 1390 [10-11]. Interoperability between the FFG OBTS and the SEA 1412 systems will be investigated in the DSTO JOANNE task. In future, the ANZAC ships and Collins class submarines are likely to acquire DIS-compatible OBTS.

2.8 RAAF AP-3C Simulators

Under Project AIR 5276, the RAAF has acquired two simulators for the new AP-3C aircraft. These simulators comprise the 'front end', Advanced Flight Simulator (AFS) and the 'back end', Operational Mission Simulator (OMS). Each of these simulators have a DIS interface [6-7, 11] that will allow the simulator, if required, to become a node in a wider Australian synthetic theatre of war, in particular providing interoperability with JOANNE systems.

3. What Is Distributed Interactive Simulation (DIS)?

Connectivity is achieved when simulators are physically connected to the same network. However only when simulators interact appropriately with each other, through the use of common standards, is interoperability achieved.

Distributed Interactive Simulation (DIS) [24-27] is a (mainly US) government/industry initiative to define an interoperability infrastructure for linking simulations of various types at multiple locations to create realistic, complex, virtual worlds for the simulation of highly interactive activities. This interoperability infrastructure brings together systems built for separate purposes, technologies from different eras, products from various vendors, and platforms from various services, and permits them to interoperate. DIS exercises are intended to support a mixture of virtual entities with

Computer Generated Forces (CGF) computer controlled behavior, virtual entities with live operators (human-in-the-loop simulators), live entities (operational platforms and test and evaluation systems), and constructive entities (war-games and other automated simulations). DIS draws heavily on experience derived from the Simulator Networking (SIMNET) program developed by the Advanced Research Projects Agency (ARPA), adopting many of SIMNET's basic concepts and heeding lessons learned.

In order for DIS to take advantage of current and future simulations developed by different organisations, a means had to be found for assuring interoperability between dissimilar simulations. These means were developed in the form of industry consensus standards. The open forum (including government, industry, and academia) chosen for developing these standards was a series of semi-annual Workshops on Standards for the Interoperability of Distributed Simulations that began in 1989. The results of the workshops have been several IEEE standards. These standards provide application protocol, communication services and recommended implementation standards to support DIS interoperability.

DIS is also defined as: a time and space coherent synthetic representation of world environments designed for linking the interactive, free-play activities of people in operational exercises. The synthetic environment is created through real-time exchange of data units between distributed, computationally autonomous simulation applications in the form of simulations, simulators, and instrumented equipment interconnected through standard computer communicative services. These DIS Protocol Data Units, the DIS data messages that are passed on a network between simulation applications according to a defined protocol, are issued by all simulation applications participating in the same exercise. The participating simulation applications may be present in one location or may be distributed geographically [24-26].

3.1 Basic Architecture Concepts

The basic architecture concepts for DIS are [25]:

a) *No central computer controls the entire simulation exercise.* Some simulation systems have a central computer that maintains the world state and calculates the effects of each entity's actions on other entities and the environment. These computer systems must be sized with resources to handle the worst-case load for a maximum number of simulated entities. DIS uses a distributed simulation approach in which the responsibility for simulating the state of each entity rests with separate simulation applications residing in host computers connected via a network. As new host computers are added to the network, each new host computer brings its own resources.

b) *Autonomous simulation applications are responsible for maintaining the state of one or more simulation entities.* Simulation applications (or simulations) are autonomous and generally responsible for maintaining the state of at least one

entity. In some cases, a simulation application will be responsible for maintaining the state of several entities. As the user operates controls in the simulated or actual equipment, the simulation is responsible for modeling the resulting actions of the entity using a simulation model. That simulation is responsible for sending messages to others, as necessary, to inform them of any observable actions. All simulations are responsible for interpreting and responding to messages of interest from other simulations and maintaining a model of the state of entities represented in the simulation exercise. Simulations may also maintain a model of the state of the environment and non-dynamic entities, such as bridges and buildings that may be intact or destroyed.

c) *A standard protocol is used for communicating ground truth data.* Each simulation application communicates the state (which is herein called ground truth) of the entity it controls/measures (location, orientation, velocity, articulated parts position, etc.) to other simulations on the network. The receiving simulation is responsible for taking this ground truth data and calculating whether the entity represented by the sending simulation is detectable by visual or electronic means. This perceived state of the entity is then displayed to the user as required by the individual simulation.

d) Changes in the state of an entity are communicated by its controlling simulation application.

e) Perception of events or other entities is determined by the receiving application.

f) *Dead reckoning algorithms are used to reduce communications processing.* A method of position/ orientation estimation, called dead reckoning, is used to limit the rate at which simulations must issue state updates for an entity. Each simulation maintains an internal model of the entity it represents. In addition, the simulation maintains a dead reckoning model of its entity. The dead reckoning model represents the view of that entity by other simulation applications on the network and is an extrapolation of position and orientation state using a specified dead reckoning algorithm. On a regular basis, the simulation compares the internal model of its entity to the dead reckoning model of the entity. If the difference between the two exceeds a predetermined threshold, the simulation will update the dead reckoning model using the information from the internal model. At the same time, the simulation will send updated information to other simulations on the network so that they can update their dead reckoning model of the entity. By using dead reckoning, simulations are not required to report the status of their entities as often as they would otherwise.

4. What Do I Need To Know About DIS and What Parts (PDUs) Do I Need?

Specific DIS PDU information is described in detail below. This information has been summarised from the relevant IEEE 1278 documentation [25-26]. For more detailed

information the reader is encouraged to read the IEEE 1278.1 and 1278.1a documentation.

4.1 Versions of DIS

The numerical values of the PDU data fields and what they represent in the DIS PDU packets are defined in a document titled *"Enumeration and Bit Encoded Values for Use with Protocols for Distributive Interactive Simulation Applications"* [27].

Users can add new enumeration values for DIS PDU data fields into this standard. This enumerations document is updated annually and is available from the Simulation Interoperability Standards Organization World Wide Web site [27].

The latest (2003) enumerations document [27] specifies the accepted DIS Protocol Versions as shown in Table 1.

Table 1. DIS Protocol Version Numbers

DIS Version Number	DIS Protocol Version
0	Other
1	DIS 1.0 (May 1992)
2	IEEE 1278 - 1993
3	DIS 2.0.3 (May 1993)
4	DIS 2.0.4 (March 16, 1994)
5	IEEE 1278.1 - 1995
6	IEEE 1278.1a - 1998

DIS has undergone the IEEE standardisation process three times. The IEEE 1278 set of standards define an interoperable (DIS) simulated battle environment. The IEEE 1278.1 (1995) and 1278.1a (1998) standards define the DIS Protocol Data Units (PDUs) - data messages that are exchanged on a network between simulation applications. The IEEE 1278 standard describes 10 PDUs. The IEEE 1278.1 standard describes the 27 PDUs defined up to 1995. The IEEE 1278.1a standard describes the additional 40 PDUs added in 1998 - it does not contain the information available in the 1995 1278.1 standard. All DIS simulators should be able to interoperate using the latest (IEEE 1278.1a - 1998) version of DIS.

PDU types were designed to be backward compatible - new PDU types were added but the existing PDU types were generally not modified however there have been some minor changes. When DIS Version 5 (IEEE 1278.1) was released, an 8-bit data field in the PDU Header Record (the common first part of every DIS PDU network packet) was defined and populated. The 8-bit field was actually set aside as padding in earlier versions of DIS however the meaning of this (PDU Protocol Family) field and the field values were not defined until IEEE 1278.1 DIS Version 5.

The values that can populate this PDU Protocol Family field (the family of PDU protocols to which this PDU belongs) are shown in table 2 [27-28]. PDU Type values of 128 and above are specified as experimental and may be application specific. The Protocol Family numbers 129 and above contain these experimental PDUs. The 130 to 133 PDU Family values are experimental, are US Navy (BFTT) specific [28] and are not specified in the IEEE documentation [27].

Table 2. DIS Protocol Family Numbers

DIS Protocol Family Number	DIS Protocol Family
0	Other
1	Entity Information/Interaction
2	Warfare
3	Logistics
4	Radio Communications
5	Simulation Management
6	Distributed Emission Regeneration
7	Entity Management
8	Minefield
9	Synthetic Environment
10	Simulation Management with Reliability
11	Live Entity
12	Non-Real Time
129	Experimental - Computer Generated Forces
130	*Experimental – Entity Information – Field Instrumentation*
131	*Experimental – Warfare Field Instrumentation*
132	*Experimental – Environmental Object Information*
133	*Experimental – Entity Management*

4.2 DIS Protocol Families

In a DIS exercise a large variety of entities need to be represented. The location and orientation is critical for the correct representation of the entity by other simulations on the network. Inclusion of the entity velocity and acceleration parameters allows receiving simulations to (independently) accurately predict entity behaviour. A simulation may also be required to accurately model the appearance of an entity. All this information is conveyed through the DIS Entity Information/Interaction family Entity State PDU (ESPDU).

Warfare in a DIS exercise involves the firing and detonation of munitions. When an entity fires a weapon the location of the firing weapon and the type of munition fired

needs to be communicated over the network. The Fire PDU and the Detonate PDU are members of the DIS Warfare PDU family.

Representation of lasers, active electromagnetic emissions, and acoustic emissions including active counter-measures are essential in certain simulation exercises. Emitting entities simulate their emitter and output real-time operational parameters. Receiving entities can then regenerate the transmitted signal based upon the simulated emitter output data and stored database. Each receiving entity is responsible for determining if the emission is detectable. If detectable, the receiving entity will use the emission data to appropriately influence its detection equipment or simulation of that equipment.

DIS exercise management is also desirable. Individual entities within a simulation need to be controllable as does the starting, pausing, restarting and stopping of simulation applications. The Exercise Management PDU family handles exercise management in DIS.

Radio and Intercom communications are another important (and expensive) part of a simulator. This functionality has been included in DIS in the Radio Communications PDU family to allow communications interoperability between simulators.

4.3 The Entity Information / Interaction PDU Family

4.3.1 The Entity State PDU

The Entity State PDU (ESPDU) communicates information about an entity's state including the appearance and location of the entity. Also included is state information that is necessary for receiving simulation applications to represent the issuing entity in the simulation applications own simulation [IEEE 1278.1 - 1995].

The Entity State PDU contains the following information:

a) Identification of the entity that issued the ESPDU
b) Identification of the force to which the entity belongs
c) The entity type being represented by the ESPDU
d) Information about the location of the entity in the simulated world including location, velocity, orientation etc.
e) Dead reckoning algorithm used
f) Additional information about the entity including appearance (normal, smoking, on fire, etc.), markings, articulated parts information, etc.

4.3.2 Dead Reckoning

Dead reckoning is a method used to estimate the position and/or orientation of an entity based on a previously known position and/or orientation and estimates of time

and motion. Entity State PDUs can be responsible for much of the bandwidth used by a simulator. Dead reckoning is used to reduce the rate at which Entity State PDUs are issued.

Each simulation application maintains two state models of each entity it is representing in support of the dead reckoning process. One model is the internal model used by the simulation application to represent its entity. The other model is the dead reckoning model of the entity it is representing. Certain thresholds are used to determine if the entity's actual position/orientation has varied an allowable amount from its dead reckoned position/orientation. When the entity's actual position/orientation has varied from the dead reckoned position/orientation by more than a threshold value, the simulation application issues an Entity State PDU to communicate the entity's actual position and orientation to other simulation applications. The simulation application uses the same information communicated to other simulation applications to update its dead reckoning model of its entity. Since DIS PDUs are broadcast all other simulation applications also receive the updated PDU.

Each simulation application maintains a dead reckoning model of the position/orientation of entities that are of interest (within sight or range) as specified by the dead reckoning model in use. When the simulation application receives a new update from one of the entities it is dead reckoning, it corrects its dead reckoning model according to the updated position/orientation, velocity, and acceleration information. Smoothing techniques may be used to eliminate jumps that occur in a visual display when the dead reckoning position/orientation of an entity is corrected using more recent position/orientation data.

4.3.3 Issuing And Receiving Entity State PDUs

A simulation issues an Entity State PDU when:

a) The discrepancy between an entity's actual state (as predicted by the entity simulation's own internal high-fidelity model) and its dead reckoned state exceeds a predetermined threshold
b) The entity's appearance changes
c) The ESPDU's dead reckoning algorithm has changed
d) The predetermined real-world "Heart Beat" time has elapsed since the last Entity State PDU was issued
e) The entity ceases to exist in the synthetic environment

On receipt of an Entity State PDU a simulation application should determine whether the entity is being accurately represented. If not the simulation application should use the information contained in the latest Entity State PDU to remodel the position, orientation, and appearance of the relevant entity.

If a deactivated appearance ESPDU is received or if a predetermined length of time has elapsed since any entity's last Entity State PDU then all simulations should remove that entity from the exercise.

4.3.4 The Collision PDU

Throughout a simulation exercise, information associated with the interactions that take place between entities needs to be exchanged. In the event that two entities collide (or an entity collides with another object such as a building in the simulated world) the simulations controlling the entities must be informed of the collision. A message (the Collision PDU) about the collision is sent by each simulation application when it detects that its entity has collided with another entity. Each simulation application determines the damage to its own entity based on information in the collision message.

The Collision PDU contains the following information:

a) Identification of the entity that issued the PDU
b) Identification of the other entity involved in the collision
c) Collision type
d) Collision location with respect to entity location, and
e) Further information to allow damage determination

4.4 The Warfare PDU Family

Weapons effects in a DIS exercise are communicated through the use of the Warfare PDUs – the Fire PDU and the Detonation PDU.

4.4.1 The Fire PDU

The Fire PDU is issued when a weapon is fired and contains the following information:

a) Identification of the entity that fired the weapon.
b) If known identification of the intended target entity.
c) Identification of the tracked munition fired.
d) Information required to predict the path and impact of the munition such as the munition launch location, munition, warhead and fuse types, quantity and rate at which the munition was fired, initial munition velocity and range, etc.

If simulation entities can detect and react to the munition during the munition's travel to effect the outcome of the simulation, the owner of the munition must immediately issue an Entity State PDU describing the munition (ie the munition is represented as an entity) once the Fire PDU has been issued. Otherwise no Entity State PDUs need be issued for the munition.

On receipt of a Fire PDU a simulation application can use the Fire PDU information to represent any (visual and aural) effects required such as muzzle flash, noise, smoke etc.

4.4.2 The Detonation PDU

The Detonation PDU is normally issued by the same simulation application that initially generated the munition or its firing. The Detonation PDU is issued when a munition impacts or detonates and contains the following information:

a) Identification of the entity issuing the PDU.
b) Identification of the target entity if an entity has been impacted.
c) Identification of the munition being detonated.
d) Information required to represent the impact or detonation of the munition including location, munition, warhead and fuse types, quantity and rate at which the munition was fired, munition detonation/impact velocity, target entity detonation location, detonation result, etc.

A munition may impact or detonate on a specific entity, on a specific terrain or the munition may detonate without effecting a specific entity or terrain.

On receipt of a Detonation PDU a simulation application can use the information contained within this PDU to represent any (visual and aural) effects that may be produced by the detonation or impact of the munition. The receiving simulation application can also use the information contained within the Detonation PDU to determine damage that may have been received by the target entity as a result of the impact or detonation.

If the munition was represented as an entity the Detonation PDU must be followed by a final munition Entity State PDU with the appearance field set to "Deactivated" (ie Delete Entity).

4.4.3 Summary for the Entity Information/Interaction and Warfare PDU Families

The Entity State PDU, the Fire PDU and the Detonation PDU are the fundamental DIS simulation PDUs. The Entity State PDU distributes the basic information (identification, location, velocity, acceleration, orientation, etc.) describing the behaviour of an entity. The Fire and Detonate PDUs describe the warfare interactions of entities and should be supported by all simulators because these PDUs are crucial from an After Action Review Debriefing point of view.

Although probably not strictly required for an air domain scenario, the Collision PDU should be required for land or maritime entity scenarios and is therefore included in the recommended set of PDUs.

4.5 The (Core) Simulation Management PDU Family

Simulation Management may or may not be required for participation in an exercise, depending upon the requirements of each exercise. Any computer on the DIS network may perform simulation management. An exercise may have one such Simulation Manager (SM), or multiple SMs. Any single entity may interact with one or multiple Simulation Managers during an exercise, or none at all. Functions of simulation management include starting, restarting, pausing, and stopping of an exercise; creating and removing entities from an exercise; and collecting and distributing data with simulation applications.

4.5.1 The Start / Resume PDU

The Start/Resume PDU tells a simulation (or a simulation entity) that it is to leave a Stopped/Frozen state and begin participating in a simulation exercise.

The Start / Resume PDU contains the following information:

a) The identification (Site, Application, and Entity Identifier numbers) of the application (entity) from which the Start / Resume PDU originated.
b) The identification of the application (entity) for which the Start / Resume PDU is intended.
c) Real-World Start / Resume time.
d) Simulation Start / Resume time.
e) A unique Start /Resume Request Identifier code.

4.5.2 The Stop / Freeze PDU

The Stop/Freeze PDU tells a simulation (or a simulated entity) that it shall leave a Simulating state and enter a Stopped/Frozen state.

The Stop / Freeze PDU contains the following information:

a) The identification (Site, Application, and Entity Identifier numbers) of the application (entity) from which the Stop / Freeze PDU originated.
b) The identification of the application (entity) for which the Stop / Freeze PDU is intended.
c) Real-World Stop / Freeze time.
d) The reason the simulation or entity was stopped / frozen.
e) The *Frozen Behaviour* of the Stopped / Frozen simulation or entity.
f) A unique Stop /Freeze Request Identifier code.

4.5.3 The Acknowledge PDU

The Acknowledge PDU is issued by a receiving simulation to verify to the SM that the original Start / Resume or Stop /Freeze PDU was received.

The Acknowledge PDU contains the following information:

a) The identification (Site, Application, and Entity Identifier numbers) of the application (entity) from which the Acknowledge PDU originated.
b) The identification of the application (entity) for which the Acknowledge PDU is intended.
c) An Acknowledge Flag indicating what type of message has been acknowledged.
d) A Response Flag indicating whether or not the receiving simulation or entity was able to comply with the request and for what reason.
e) A matching unique Request Identifier code to that received in the original Start / Resume or Stop /Freeze PDU.

4.5.4 The Comment PDU

The Comment PDU can be used by any simulation application to input a message into the DIS data stream to be used as a comment, error or test message or as a position marker in a stored DIS data log file.

The Comment PDU contains the following information:

a) The identification (Site, Application, and Entity Identifier numbers) of the application (entity) from which the Comment PDU originated.
b) The identification of the application (entity) for which the Comment PDU is intended.
c) Fixed and / or variable size data records.

No response is required on receipt of the Comment PDU.

4.6 Other (Core) Simulation Management PDUs

Simulation management PDU functions include: starting, restarting, pausing, and stopping an exercise; the creation and removal of entities from an exercise; and collection and distribution of data with simulation applications.

The US Navy Battle Force Tactical Training (BFTT) program defines a *Core Set of Simulation Management PDUs* [28] needed for exercise control as the Start/Resume, Stop/Freeze, Action Request Action Response and Acknowledge PDUs. These PDUs allow simulations to transition from the Stopped State to the Simulating State and vice-versa.

4.6.1 The Action Request PDU

The Action Request PDU is used by the SM to request that a specific action be performed by a simulation entity. Information required for the entity to perform the requested action is included in the data fields of this PDU.

The Action Request PDU contains the following information:

a) The identification (Site, Application, and Entity Identifier numbers) of the application (entity) from which the Action Request PDU originated
b) The identification of the application (entity) for which the Action Request PDU is intended.
c) A Request ID.
d) An Action ID.
e) Fixed and / or variable size data records.

Upon receipt of the Action Request PDU, the receiving entity sets the appropriate parameters as specified. It is up to the entity receiving the Action Request PDU to determine which (if any) parameters described in the Action Request PDU it can set. The receiving entity then responds with an Action Response PDU.

4.6.2 The Action Response PDU

The Action Response PDU is issued on receipt of an Action Request PDU.

On receipt of the Action Response PDU, the receiving simulation application (the originator of the Action Request PDU) may note that the action request was received and the status of that request.

4.6.3 The Set Data PDU

The Set Data PDU is used by the SM to set or change certain parameters of an entity.

The Set Data PDU contains the following information:

f) The identification (Site, Application, and Entity Identifier numbers) of the application (entity) from which the Set Data PDU originated
g) The identification of the application (entity) for which the Set Data PDU is intended.
h) Set Data Request ID.
i) Fixed and / or variable size data records.

Upon receipt of the Set Data PDU, the receiving entity sets the appropriate parameters as specified in the PDU. It is up to the receiving entity of the Set Data PDU to

determine which (if any) parameters described in the Set Data PDU it can set. The receiving entity then responds with a Data PDU.

4.6.4 The Data PDU

A Data PDU is issued in response to a Data Query PDU or a Set Data PDU. When the Data PDU is issued in response to the Set Data PDU, it verifies the receipt of the Set Data PDU by returning the parameter values that were set in response to the Set Data PDU. Parameters that were set in the simulation to the same values as in the Set Data PDU are set to those values in the Data PDU. Parameter values that were set to different values in the simulation than requested in the Set Data PDU are set to their actual values in the Data PDU. Parameters to which the receiving entity cannot comply are not included in the Data PDU response.

On receipt of the Data PDU, the receiving simulation management computer may record the information for simulation management purposes.

4.6.5 How Are the Set Data, Data, Action Request and Action Response PDUs related?

The data field structure of the Data PDU is identical to the Set Data PDU. Once the relevant parameters have been populated as required to the Data PDU fields the only difference between the Data PDU and the Set Data PDU is that the Originating Entity ID data in the Set Data PDU becomes the Receiving Entity ID data in the Data PDU and vice-versa.

The structure of the Data PDU is identical to the Set Data PDU. Therefore once the Set Data PDU has been implemented the additional cost to implement the Data PDU should be small.

The data field structure of the Action Request PDU is identical to the Action Response PDU. Once the relevant parameters have been populated as required to the Action Request PDU data fields the only difference between the Action Request PDU and the Action Response PDU is that the Originating Entity ID data in the Action Request PDU becomes the Receiving Entity ID data in the Action Response PDU and vice-versa.

The data field structures of the Set Data/Data PDUs are almost identical to the data field structures of the Action Request/Action Response PDUs. The field size bit patterns and the locations of these data fields in the PDUs are exactly the same in all four PDUs. The only difference between these PDUs is that an unused 32-bit padded field in the Set Data and Data PDUs becomes a 32-bit Action ID field in the Action Request and Action Response PDUs.

The Action Request PDU is meant to be used to request that a specific action be carried out by an entity in a simulation.

The Set Data PDU is often used to remotely start an application over the network. The remotely started application can be populated with data via the Set Data PDU fixed and/or variable sized data records.

The enumeration values used in the Request ID field in the Set Data PDU can be used to request a user-defined action. These Request ID field enumeration values have not been predefined in any DIS documentation. The specifically targeted applications are supposed to understand what action is required. The USN BFTT (but not the IEEE) documentation indicates that *"the Data PDU shall respond with all zero's in the Request ID field when it cannot comply to a Set Data PDU"* [28]. Therefore any non-zero value can be used in the Set Data PDU and Data PDU Request ID field.

The application from which the Set Data PDU originates can be designed with the capability to start or modify the behaviour of remote applications without having any knowledge of what functions the remote applications carry out. This can be done using configuration files. This (very useful) capability could be used to start an application (eg a DIS Data Logger) on a particular (remote) computer using a particular port number on the DIS network thus simplifying considerably network application configuration management.

The Set Data PDU could also be used to modify the behaviour of an already started application (rewind/replay the DIS Data Logger, etc).

In another example a simulation application could start in a normal mode but be reset to an alternate, replay mode by a Set Data PDU when a DIS Data Logger replays recorded DIS data.

In normal mode a simulator application could broadcast the settings or values of dials or gauges by sending out a Set Data PDU or an Action Request PDU with the relevant dial or gauge data embedded in the PDU data fields. If this simulation application is (re)set to a replay mode (using a Set Data PDU) the simulator could set these dials or gauges to the values specified in the replayed Set Data or Action Request PDUs and thus DIS could be used to record and replay the settings of such dials or gauges. DIS was never specifically designed with this capability in mind however it can be achieved because a DIS Data Logger should record all DIS PDUs including the Set Data and Action Request PDUs that contain the dial or gauge settings and the interpretation of the information stored in the Set Data or Action Request PDUs is left up to individual simulation application.

Although the USN BFTT program considers the Action Request PDU and the Action Response PDU to be core management PDUs, if the specific entity actions supported by these PDUs are not required then the Action Request PDU and the Action Response PDU are not necessary and the Start/Resume/Stop/Freeze capabilities may be all that is required.

The application startup and modification capabilities of the Set Data and Data PDUs appear to be very useful to enable remote management of applications over the network.

4.6.6 Summary for the Simulation Management PDU Family

Simulation applications should be able to be managed in a DIS exercise with many participants. Not all simulation applications should need to be able to function as Simulation Managers. Therefore all simulation applications should support the reception of (and appropriate reaction to) the Start/Resume and Stop/Freeze PDUs and transmit the required response Acknowledge PDU.

The Comment PDU is a fundamental PDU from an After Action Review Debrief point of view.

The Set Data, Data, Action Request and Action Response PDUs are not considered as fundamental in providing interoperability with other DIS simulators. They are however, potentially, useful PDUs in enhancing the record and replay capability of a simulator and the ability of a simulation application to remotely start, stop and modify the behaviour of other applications in ways that DIS was never specifically designed to do. Each individual simulator should carefully examine the usefulness of these PDUs.

4.7 The Distributed Emission Regeneration PDU Family

4.7.1 The Electromagnetic Emission PDU

The Electromagnetic Emission PDU is used to communicate active electronic warfare emissions and countermeasures. Radio communications and designator tracking are handled by separate PDUs.

The Electromagnetic Emission PDU contains the following information:

a) Identification of the emitting entity.
b) Number of emitter systems for which information is being provided.
c) For each emitter system the relative emitter-entity location, the number of beams, the emitter name, function, identification number, frequency, frequency range, power, pulse repetition frequency, pulse width, and additional beam and track/jamming parameters are provided.

On receipt of an Electromagnetic Emission PDU the receiving simulation application determines if the emission is detectable and uses the information in the PDU to determine the behaviour of the emission detection (eg electronic warfare) equipment controlled by that simulation application.

4.7.2 The IFF/ATC/NAVAIDS PDU

The IFF / ATC/NAVAIDS PDU includes the following information:

a) Identification of the entity emitting the IFF/ATC/NAVAIDS signals.
b) Identification of the type of system emitting the signals.
c) The status of the emitting system.
d) Which modes of signals the system is capable of emitting and the codes transmitted for these modes.

Additional, optional, IFF/ATC/NAVAIDS PDU information layers can convey information regarding:

a) The electromagnetic characteristics of a typical emission - power, frequency, pulse width etc.
b) The rate at which signals are emitted.
c) Identification of which signals are responses to which previous signals.

The receiving simulation is responsible for determining if the IFF/ATC/NAVAIDS information is detectable.

4.7.3 Summary for the Distributed Emission Regeneration PDU Family

Within the next 5 years most, if not all, ADF platforms of significance will have an Electronic Warfare capability and therefore support for the Distributed Emission Regeneration Family PDUs should be considered as essential.

However the fact that the USN Battle Fleet Tactical Training project and the RAN FFG Upgrade Project have both added extra experimental Electromagnetic Emission PDUs indicates that the IEEE 1278.1a standard may not fully support a modern Electronic Warfare capability.

4.8 The Radio Communications PDU Family

4.8.1 The Transmitter PDU

The Transmitter PDU is used to communicate the state of a radio transmitter.

The Transmitter PDU includes the following information:

a) The identification of the entity that contains the radio transmitter
b) The identification of the particular transmitter (and its type) being described
c) State of the transmitter (such as off, on but not transmitting or on and transmitting)
d) Source of radio input (pilot, co-pilot, etc.)

e) Absolute and relative radio antenna location
f) Radio transmitter parameters such as frequency, bandwidth, power, modulation, etc.
g) Secure communications parameters such as equipment type and cryptographic key.

A Transmitter PDU is issued by the radio transmitter simulation application when:

a) A predetermined (heart beat) length of time has elapsed since issuing the last Transmitter PDU
b) A relevant parameter has changed or exceeded a required threshold

When a transmission is initiated, a Transmitter PDU is issued before the first Signal PDU of the transmission. When a transmission is concluded, a Transmitter PDU will follow the final Signal PDU of the transmission.

On receipt of a Transmitter PDU the receiving radio simulation application determines what, if any, special effects (no reception, clear reception, level of noise or jamming etc.) are applied to the received radio transmission signal. If the transmission is to be received and demodulated the receiving radio simulation application must then start to process the data in any Signal PDUs received from that particular radio transmitter – see below.

4.8.2 The Signal PDU

The Signal PDU contains the content of a radio transmission. This content may be digitised audio or other data.

The Signal PDU contains the following information:

a) Identification of the entity that is the source of the transmission
b) Identification of the particular transmitter that is transmitting
c) The encoding scheme used
d) The type of signal message transmitted (digitised voice, Link 11, Link 16 etc.)
e) The sample rate
f) The actual digitised voice or TDL data

For voice or TDL data as soon as a transmitter is turned on (so that a Transmitter PDU with a state of on and transmitting is issued) a constant stream of Signal PDUs is issued to enable an uninterrupted flow of signal content.

On receipt of a Signal PDU the receiving application determines if it has received an associated Transmitter PDU. If the correct Transmitter PDU was received and the receiving simulation application determines that it can detect the transmission the

receiving simulation application converts the digitized data and applies any special effects required.

4.8.3 The Receiver PDU

The Receiver PDU is used to communicate the state of a particular radio receiver and it contains the following information:

a) The identification of the entity controlling the radio receiver being described
b) The identification of the particular radio receiver that is being described
c) The state of the receiver
d) The identification of the entity that is the source of the radio transmission
e) The identification of the particular radio at the source of the radio transmission

A Receiver PDU is issued by the radio receiver simulation application when:

a) A predetermined (heart beat) length of time has elapsed since issuing the last Receiver PDU
b) A relevant parameter has changed or exceeded a required threshold

No response to a Receiver PDU is required.

4.8.4 Summary for the Radio Communications PDU Family

For simulators the DIS Radio Communications PDU Family enables radio communications interoperability between simulators. Other than the IEEE 1278.1/1a Radio Communications Family PDUs no standard exists for simulator communications.

In ADF simulators only the RAN FFG Upgrade simulator and the RAAF ADGESIM simulator have provided (will provide) DIS Communications at installation. A DIS Communication capability has now been added to the HMAS Watson IOTTF and CSTT simulators and this has enabled DIS Communications interoperability between the various RAN and USN systems during CReaMS exercises [22].

Overseas most, if not all, simulators provide DIS Communications via the use of proprietary ASTi [29] hardware. Intercom PDUs were introduced in DIS version 6 (1278.1a); however before the introduction of this version of DIS, ASTi assigned all frequencies below 100,000 Hz as intercom channels. In the exercises the author has been involved in, DIS version 6 Intercom PDUs are not normally used so as to enable support of legacy DIS (version 5) communications systems.

Although the Signal PDU was originally designed to support Link, Link enumerations were not available until 2003. By this time major simulation projects implement Link by sending real Link messages around a simulation network wrapped up in the NATO

standard STANAG SIMPLE protocol. These Link messages are wrapped and unwrapped as required and are used as input to real Link devices. This is discussed in more detail in Appendix A.

DIS Communications Family PDU support in ADF DIS simulators is considered essential.

5. ADF Simulator DIS Interoperability

The following ADF training simulators currently (or will shortly) have a DIS interoperability capability:

Table 3. ADF DIS Capable Simulators

System	DIS Interface Details
RAN HMAS Watson IOTTF (FFG)	IEEE 1278.1a
RAN HMAS Watson CSTT (Anzac)	IEEE 1278.1a
RAN FFG UP	IEEE 1278.1a (Including Experimental)
RAN Seasprite	IEEE 1278.1a (Including Experimental)
RAAF AP-3C OMS	DIS Version 3 or 4 ? IST-CR-93-40 (7 March 1994)
RAAF ADGESIM	IEEE 1278.1a

5.1 The RAN HMAS Watson IOTTF Simulator

From a DIS Interface perspective the HMAS Watson Integrated Operations Team Training Facility (IOTTF), that is used as an FFG (its DDG model is no longer required) Team Trainer, is comprised of three DIS components over two networks. The two networks are the DIS Data LAN and the DIS Radio LAN. The IOTTF Ship model is connected to the DIS Data LAN via the IOTTF DIS Gateway (G/W), the ASTi DIS Communications System (DAC) is connected to the Radio LAN and the IOTTF Exercise Management Console (EMC) is connected to both LANs.

The HMAS Watson IOTTF simulator is an emulated system. Real "ship-fit" equipment is not used.

The DIS PDUs supported by each of these IOTTF components (DIS applications) are shown in Table 4. All IOTTF PDUs supported comply with the IEEE 1278.1a (DIS Version 6) DIS protocol standard [26]. A simulator can respond appropriately or completely ignore a PDU received from the network. This (Receive) interaction is

shown in the Rx column in Table 4. A simulator can convey the state of a particular internal interaction by transmitting PDUs onto the DIS network as shown in the Tx (Transmit) column in Table 4.

Table 4. DIS PDUs Supported in each IOTTF DIS Simulator Component

PDU Type	PDU Name	Rx G/W	Tx G/W	Rx EMC	Tx EMC	Rx DAC	Tx DAC
1	Entity State	✔	✔	✔	✘	✘	✘
2	Fire	✘	✔	✔	✘	✘	✘
3	Detonation	✘	✔	✔	✘	✘	✘
4	Collision	✔	✔	✔	✘	✘	✘
11	Create Entity	✘	✘	✔	✔	✘	✘
12	Remove Entity	✘	✘	✔	✔	✘	✘
13	Start/Resume	✘	✘	✔	✔	✘	✘
14	Stop/Freeze	✘	✘	✔	✔	✘	✘
15	Acknowledge	✘	✘	✔	✔	✘	✘
20	Data 1)	✔	✔	✔	✔	✘	✘
22	Comment	✘	✘	✔	✔	✘	✘
23	Electromagnetic Emission	✔	✔	✔	✘	✘	✘
25	Transmitter	✘	✘	✔	✘	✔	✔
26	Signal	✘	✘	✘	✘	✔	✔
27	Receiver	✘	✘	✔	✘	✔	✔
28	IFF/ATC/NAVAIDS	✔	✔	✔	✘	✘	✘
41	Environmental Process	✔	✔	✘	✘	✘	✘
51	Create Entity - R	✘	✘	✔	✔	✘	✘
52	Remove Entity - R	✘	✘	✔	✔	✘	✘
53	Start/Resume - R	✘	✘	✔	✔	✘	✘
54	Stop Freeze - R	✘	✘	✔	✔	✘	✘
55	Acknowledge - R	✘	✘	✔	✔	✘	✘
62	Comment - R	✘	✘	✔	✔	✘	✘
66	Collision Elastic	✔	✔	✔	✘	✘	✘
67	Entity State Update	✔	✔	✔	✘	✘	✘
	1) For internal communications only						

5.2 The RAN HMAS Watson CSTT Simulator

The DIS PDUs supported by the HMAS Watson Anzac Combat System Tactical Trainer (CSTT) are shown below in Table 5 where 1) is for internal communications only. All CSTT PDUs supported comply with the IEEE 1278.1a DIS Protocol Standard [26].

Table 5. DIS PDUs Supported in the Anzac Ship CSTT simulator

PDU Type	PDU Name	Receive	Transmit
1	Entity State	✔	✔
2	Fire	✘	✔
3	Detonation	✔	✔
4	Collision	✘	✔
11	Create Entity	✔ 1)	✘
12	Remove Entity	✔ 1)	✘
13	Start/Resume	✔	✔
14	Stop/Freeze	✔	✔
15	Acknowledge	✔ 1)	✔
20	Data	✔	✘
21	Event Report	✔	✘
22	Comment	✔ 1)	✘
23	Electromagnetic Emission	✔	✔
25	Transmitter	✔	✔
26	Signal	✔	✔
27	Receiver	✔	✔
28	IFF/ATC/NAVAIDS	✔	✔
29	Underwater Acoustic	✔ 1)	✔
31	Intercom Signal	✔	✔
41	Environmental Process	✔ 1)	✘
51	Create Entity - R	✔ 1)	✘
52	Remove Entity - R	✔ 1)	✘
53	Start/Resume - R	✔ 1)	✘
54	Stop Freeze - R	✔ 1)	✘
55	Acknowledge - R	✔ 1)	✔
56	Action Request - R	✔ 1)	✘
57	Action Response – R	✔ 1)	✔
58	Data Query – R	✔ 1)	✘
59	Set Data – R	✔ 1)	✘
60	Data – R	✔ 1)	✘
61	Event Report - R	✔ 1)	✘
62	Comment - R	✔ 1)	✘
63	Record Query – R	✔ 1)	✘
64	Set Record – R	✔ 1)	✘
65	Record - R	✔ 1)	✔

The HMAS Watson CSTT Anzac ship simulator is a "ship-fit" stimulated system that uses actual hardware present on the Anzac platforms.

5.3 The RAN FFG UP Simulator

The RAN FFG UP simulator is made up of three different systems. The Garden Island FFG Land Based Test System (FFG LBTS) is the developmental system for the real FFG On-Board Training System (FFG OBTS). The FFG Tactical Trainer (FFG TT) system is the (stimulated) training simulator to be located at the Maritime Warfare Training Centre at the HMAS Watson in Sydney.

As part of the Battle Force Tactical Training System, the US Navy is currently installing new technology combat systems in all of its major platforms. A complete shipboard system is constructed by selecting the required, common, Combat System (radars, IFF, weapons, navigation, Data Links, Electronic Warfare, communications, etc.) components supporting the hardware used on the ship. This approach is very similar to the COTS plug and play modular approach used for commodity desktop personal computers. These common components are completely independent of any ship type or class.

Training capabilities may be added to any ship (system) at any time by simply adding a simulator or stimulator to the On-Board Training network. A ship (system) may train in stand-alone mode in a common synthetic environment, connect to other ships, joint or coalition platforms meeting the required interoperability standards. Combat system operators may be trained individually or as a team.

These common, USN, BFTT Combat System components use BFTT (mostly IEEE) DIS PDUs as their backbone communication protocols. The USN has its own BFTT DIS standard [28]. The BFTT standard includes all the IEEE 1278.1a standard PDUs [26]. There are however extra experimental PDUs and some non-IEEE standard PDUs (eg a version 5 IFF PDU). As long as the non-IEEE standard PDUs are not used, real BFTT, ship combat (On-Board Training) systems are IEEE DIS compliant. The BFTT Enumerations (DIS PDU data field values) may be different from (and possibly incompatible with) the SISO Enumerations [27-28].

A high fidelity (shore based), stimulated training system (simulator) can be easily constructed from a set of these common, combat system components.

These simulator components are exactly the same as those used on a ship and therefore behave and interoperate correctly - they are high fidelity stimulated components. Where a stimulator system is not available, an emulation approach can be used. The actual set of common components used will reflect the systems for which the training is required. A diagram of the USN BFTT Architecture is shown in Figure 1.

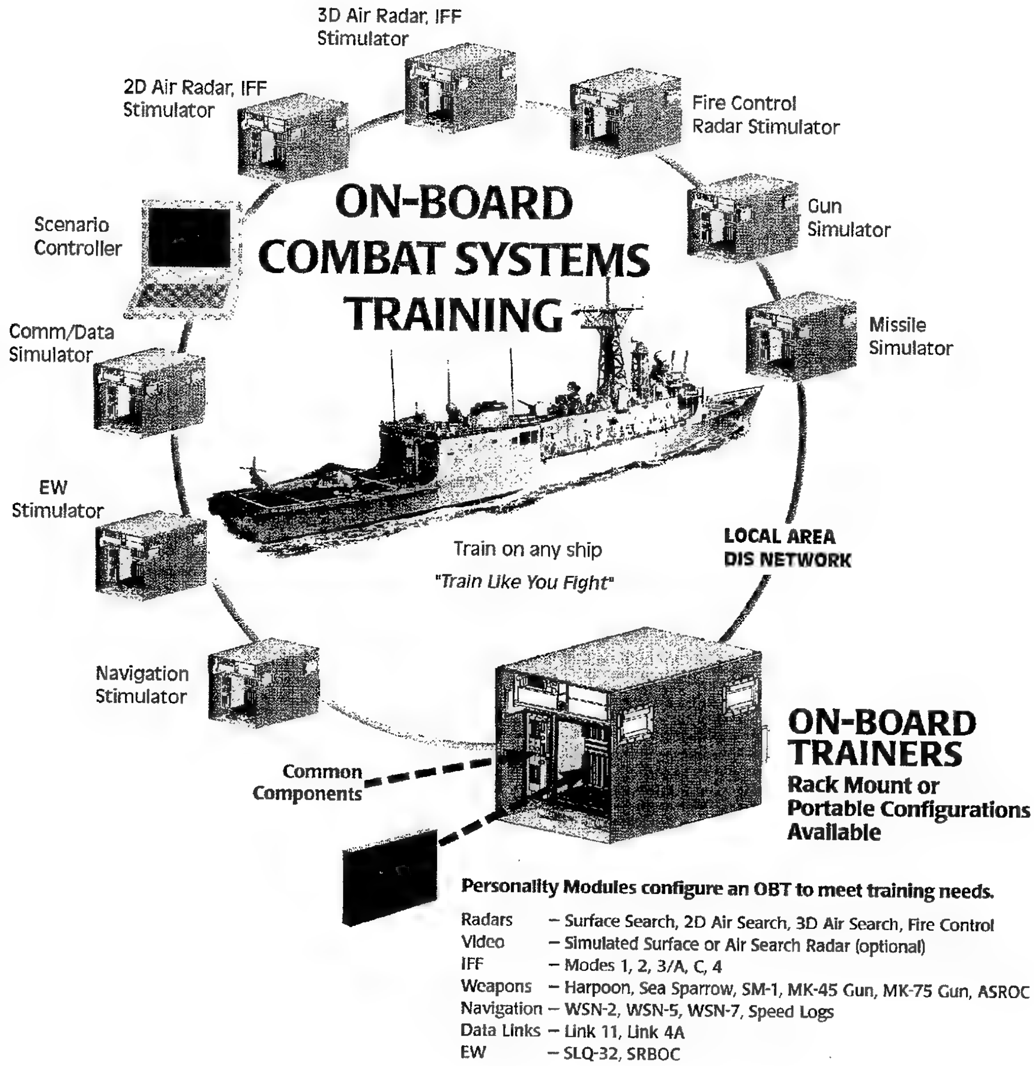

Figure 1. USN BFTT Architecture

The FFG Upgrade project uses a more modern version of the technology used in the USN BFTT program. The same USA AAI Corporation [30] is working on both the BFTT and FFG UP projects.

The DIS PDUs supported by the RAN FFG UP Project are shown below in Table 6. The IEEE 1278.1a (DIS Version 6) DIS Protocol Standard has allowance for PDU types up to 127 (those that already exist) as standardised pre-defined PDUs. PDU type values 129 and above are reserved and can be used by projects for their own purposes. The FFG UP Project, private, experimental PDUs are also shown in Table 6.

Table 6. DIS PDUs Supported in the FFG UP Simulator

PDU Type	PDU Name	Receive	Transmit
1	Entity State	✔	✔
2	Fire	✘	✔
3	Detonation	✔	✔
4	Collision	✔	✔
13	Start/Resume	✔	✔
14	Stop/Freeze	✔	✔
15	Acknowledge	✔	✔
18	Data Query	✔ 1)	✔ 1)
19	Set Data	✔ 1)	✔ 1)
20	Data	✔	✘
22	Comment	✔ 1)	✔ 1)
23	Electromagnetic Emission	✔	✔
25	Transmitter	✔	✔
26	Signal	✔	✔
27	Receiver	✔	✔
28	IFF/ATC/NAVAIDS	✔	✔
29	Underwater Acoustic	✔	✔
220	Underwater Environment	✔	✔
221	RAN FFG UP Chaff	✔	✔
230	BFTT Surface Ship Status (S4)	✔ 1)	✔ 1)
231	BFTT Chaff	✔	✔
232	BFTT Environment	✔	✔
233	BFTT Jammer	✔	✔
235	BFTT Supplemental Electromagnetic Emission (SEE)	✔	✔
240	RAN FFG UP Trainer Status	✔ 1)	✔ 1)
241	RAN FFG UP Fused Track	✔ 1)	✔ 1)
tbd	RAN FFG UP Electromagnetic Emission	✔	✔
tbd	RAN FFG UP Link-11 / Link-16	tbd	tbd
	1) For internal communications only		

5.4 The RAAF AP-3C OMS Simulator

The DIS PDUs supported in the RAAF AP-3C Operational Mission System (OMS) simulator are shown in Table 7 [31].

According to the documentation available [31] the AP-3C OMS DIS PDUs are compliant with "Standard for Distributed Interactive Simulation - Application Protocols, Version 3.0 Working Draft, IST-CR-93-40, 7 March, 1994".

Table 7. DIS PDUs Supported in the RAAF AP-3C OMS Simulator

PDU Type	PDU Name	Supported
1	Entity State	✔
2	Fire	✔
3	Detonation	✔
4	Collision	✔
13	Start/Resume	✔
14	Stop/Freeze	✔
15	Acknowledge	✔
23	Electromagnetic Emission	✔
?	Acoustic (?)	✔

Table 8 shows the IST (Institute for Simulation and Training) Report Numbers for DIS Versions 3 and 4 Standards Documentation.

Table 8. IST Report Numbers for DIS Versions 3 and 4 Standards Documentation

DIS Version Number	DIS Version	IST Report Number
3	DIS 2.0.3 (May 28, 1993)	IST-CR-93-15
4	DIS 2.0.4 (March 16, 1994)	IST-CR-94-50

The DIS PDUs in the AP-3C OMS simulator may have been developed using a set of documentation published prior to the IEEE standardisation process and some PDUs may not be IEEE compliant.

According to the AP-3C BAE documentation:

"The Acoustic PDU communicates acoustic information and sonar system characteristics. This is a CAE PDU implemented in addition to the DIS standard, it is a CAE standard PDU and is used to inform the simulations of the acoustics and sonar system characteristics data of all surface and subsurface players in the scenario. If an external simulator does not use this PDU then it will be ignored [31]."

There is no (Underwater) Acoustic PDU in IEEE DIS Version 3 or 4. The Underwater Acoustic PDU first appeared in the 1998 IEEE 1278.1a DIS Version 6 standard.

5.5 The RAAF VAE ADGESIM Simulator

The RAAF Virtual Air Environment Air Defence Ground Environment Simulator (ADGESIM) [8-9] is used at RAAF Williamtown and RAAF Darwin to train Air Defence Controllers. ADGESIM was developed by DSTO after industry could not deliver a suitable capability within a suitable time frame.

ADGESIM uses an architecture similar to that used in the US Navy's BFTT Project and the Australian Navy's FFG Upgrade Project. All ADGESIM components interoperate on a DIS network and the PDUs (the backbone communications protocol packets) from the DIS network are used to stimulate real system components. ADGESIM is a high fidelity, stimulated system and Air Defence Controllers report that they cannot differentiate between the behaviour of the training system and the behaviour of the real system.

ADGESIM (and its components) support a basic set of PDUs necessary to achieve the required Air Defence Controller training outcomes. The DIS PDUs supported in the RAAF ADGESIM simulator are shown in Table 9. Not all ADGESIM components support all the PDUs listed in table 9 and the various PDU types are being implemented as they are required, and when time permits, in the various ADGESIM components.

Table 9. DIS PDUs Supported in the DSTO RAAF ADGESIM Simulator

PDU Type	PDU Name	Supported
1	Entity State	✔
2	Fire	✔
3	Detonation	✔
19	Set Data	✔
23	Electromagnetic Emission	✔
25	Transmitter	✔
26	Signal	✔
27	Receiver	✔
28	IFF	✔

The BFTT and FFG UP Projects use a common component, reconfigurable, COTS, plug and play modular approach. Although these common components are COTS, they will mostly still comprise, or be built upon, proprietary software and hardware.

The ADGESIM simulator takes this approach further. As well as using the IEEE DIS PDUs as the backbone communication protocols, all ADGESIM components are software only applications (they require no specialist hardware eg. ship fit consoles), run on commodity personal computer hardware and software (Microsoft Windows XP Pro), and are developed using the latest version, industry standard Microsoft (Visual Studio.NET 2003) C++ compiler.

A diagram of the ADGESIM architecture is shown in Figure 2.

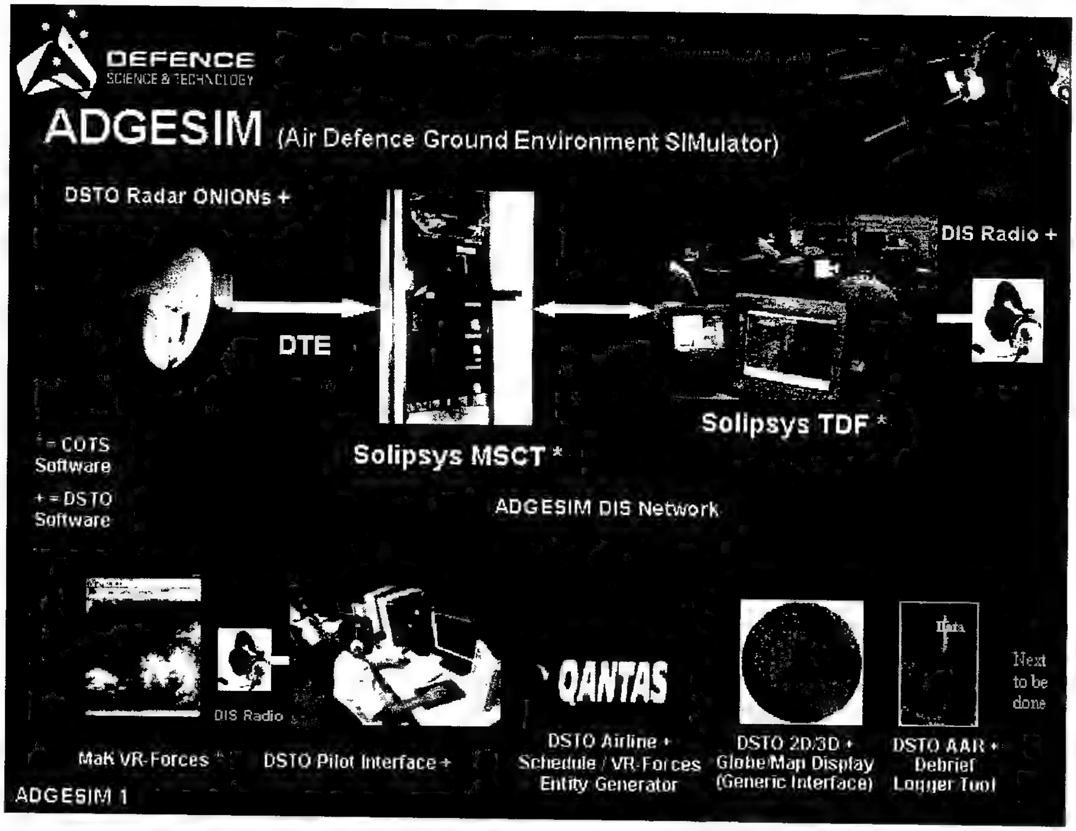

Figure 2. RAAF VAE ADGESIM Simulator Architecture

All ADGESIM components are reusable, that is, they can be used on other (ADF) DIS compliant simulators without (or with very little) modification because, unlike the more recent Higher Level Architecture (see detailed discussion in section 7), the underlying backbone communication DIS PDU data structures [25-26] and the data contained within the DIS PDUs [27] have been standardised by the IEEE.

ADGESIM is low cost to purchase, cost effective to develop and maintain, is high fidelity and, if required because it runs on commodity hardware and software, will be long lived. This low cost, cost effective, stimulated and long-lived simulator philosophy and approach will the subject of a separate report [32].

6. The Recommended, Minimum, Basic Set of DIS PDUs for a Simulator

The objective of having a recommended, minimum, basic set of DIS PDUs for a simulator is:

a) To reduce the analysis phase to determine what PDUs are required for any simulator, and
b) To ensure that every ADF simulator implements a minimum set of DIS PDUs to allow sufficient application protocol interoperability to enable that simulator to participate in a DIS Wide Area Network training exercise at the time the simulator is accepted by the Commonwealth without an expensive, after acceptance (eg Engineering Change Proposal (ECP)), modification thus reducing cost and risk to the simulator project (ie the Commonwealth).

During the simulator design phase, an analysis of the platform's capabilities should be carried out to determine the capabilities and DIS PDUs necessary to meet the training outcomes required. However most military simulators should have a minimum basic set of DIS PDUs to provide a sufficient level of application protocol interoperability, to ensure that it can participate in a DIS, Wide Area Network, training exercise.

The type of simulator requiring this minimum, basic set of DIS PDUs is assumed to simulate a platform that can carry weapons, have an electronic warfare capability and require radio/intercom communications. A single engine Cessna may not carry any weapons and may have no electronic warfare capability.

Comparing the DIS PDUs supported by major platform simulators will give an indication of such a common set of PDUs - this is done in Section 6.1 below.

Analysing the recorded DIS PDU traffic from a major (coalition) exercise should also give an indication of such a common set of PDUs - this is discussed in Section 6.2.

The results of these two alternative methods are combined in section 6.3 that presents a recommended, minimum basic set of DIS PDUs for a simulator.

6.1 Comparing RAN and RAAF Simulator DIS Interfaces

The PDUs supported by DIS Interfaces of ADF simulators are compared in Table 10, and the recommended, minimum, basic set of DIS PDUs (discussed in section 6.3) are shown in shaded cells in Table 10.

PDU types that are only supported by simulators for internal simulator component communications are marked as not supported (eg. ✘). PDU types that should be added

Table 10. DIS PDUs Supported in RAN and RAAF simulators

PDU Type	PDU Name	IOTTF	CSTT	FFG UP	AP-3C OMS	ADGESIM
1	**Entity State**	✔	✔	✔	✔	✔
2	**Fire**	✔	✔	✔	✔	✔
3	**Detonation**	✔	✔	✔	✔	✔
4	**Collision**	✔	✔	✔	✔	✘
11	Create Entity	✔	✘	✘	✘	✘
12	Remove Entity	✔	✘	✘	✘	✘
13	**Start/Resume**	✔	✔	✔	✔	✘
14	**Stop/Freeze**	✔	✔	✔	✔	✘
15	**Acknowledge**	✔	✔	✔	✔	✘
19	Set Data	✘	✘	✘	✘	✔
20	Data	✘	✔	✔	✘	✘
22	**Comment**	✔	✘	✘	✘	✘
23	**Electromagnetic Emission**	✔	✔	✔	✔	✔
25	**Transmitter**	✔	✔	✔	✘	✔
26	**Signal**	✔	✔	✔	✘	✔
27	**Receiver**	✔	✔	✔	✘	✔
28	**IFF/ATC/NAVAIDS**	✔	✔	✔	✘	✔
29	Underwater Acoustic	✘	✔	✔	✘	✘
31	Intercom Signal	✘	✔	✘	✘	✘
41	Environmental Process	✔	✘	✘	✘	✘
51	Create Entity - R	✔	✘	✘	✘	✘
52	Remove Entity - R	✔	✘	✘	✘	✘
53	Start/Resume - R	✔	✘	✘	✘	✘
54	Stop Freeze - R	✔	✘	✘	✘	✘
55	Acknowledge - R	✔	✔	✘	✘	✘
57	Action Response - R	✘	✔	✘	✘	✘
62	Comment - R	✔	✘	✘	✘	✘
65	Record - R	✘	✔	✘	✘	✘
66	Collision Elastic	✔	✘	✘	✘	✘
67	Entity State Update	✔	✘	✘	✘	✘
220	FFG Underwater Environment	✘	✘	✔	✘	✘
221	RAN FFG UP Chaff	✘	✘	✔	✘	✘
231	BFTT Chaff	✘	✘	✔	✘	✘
232	BFTT Environment	✘	✘	✔	✘	✘
233	BFTT Jammer	✘	✘	✔	✘	✘
235	BFTT Supplemental Electromagnetic Emission	✘	✘	✔	✘	✘
tbd	RAN FFG UP Electromagnetic Emission	✘	✘	✔	✘	✘
tbd	RAN FFG UP Link -11/16	✘	✘	tbd	✘	✘
?	Acoustic (?)	✘	✘	✘	✔	✘

(ie the PDU has not been implemented in the simulator) or modified (not compatible) in any particular simulator compared in Table 10 are shown in red eg ✘.

The following can be concluded from table 10:

a) The Entity State PDU is the most fundamental DIS PDU and is used by all simulators.
b) Similarly the Fire and Detonation PDUs are supported by all simulators although the FFG UP simulator ignores received Fire PDUs (see Table 6) as this PDU most likely has no effect on any FFG UP sub-systems. It should be important for all systems to transmit the Fire PDU to allow for visual and aural effects where required, however it may be most important for systems to transmit Fire PDUs for use in DIS After Action Review Debriefing tools.
c) The Collision PDU is supported by all simulators except the ADGESIM simulator. The ADGESIM simulator does not have an ownship entity therefore ADGESIM itself cannot collide with anything and has no requirement for a Collision PDU [8-9]. Currently ADGESIM only generates air entities and collision information is probably more important for land and sea entities as a collision with an air entity would most likely result in the destruction of that air entity. To support sea and land entities from within ADGESIM, each ADGESIM application will have Collision PDU support added if required and when time permits.
d) All simulators support the Start/Resume, Stop/Freeze and Acknowledge Simulation Management Family PDUs except the ADGESIM simulator. Support for these management PDUs will be added to ADGESIM. Simulators do not need to be able to control an exercise (transmit the Start/Resume and Stop/Freeze PDUs and react to the Acknowledge PDU) however it is important to be able to be managed by responding to Start/Resume and Stop/Freeze PDUs and transmitting Acknowledge PDUs.
e) The Set Data PDU is only supported by the ADGESIM simulator to communicate with other (DIS) applications on the DIS network. Because it is a DIS PDU it will be recorded by a DIS Data Logger application and remote applications will be correctly restarted when data (including the Set Data PDU) is replayed by the DIS Data Logger. Because the Set Data PDU is a simple PDU, it is easy to add this capability to a simulator.
f) Similarly the Comment PDU is a simple, easy to implement, useful PDU as it allows instructor and/or student comments to be recorded and played back (correctly synchronised along with all the other DIS data) by a DIS Data Logger. The Comment PDU capability would be very useful in a DIS After Action Review Debriefing process.
g) The Electromagnetic Emission PDU is supported by all simulators and is required to enable Electronic Warfare training.
h) The IFF/ATC/NAVAIDS PDU is supported by all simulators except the AP-3C simulator.

i) The Radio Communications Family (Transmitter, Signal and Receiver) PDUs are supported by all simulators except the AP-3C simulator. These PDUs are fundamental in that they allow simulators to interoperate using their simulator radio and intercom systems via an IEEE standardised mechanism.
j) The Underwater Acoustic PDU is not considered as part of the Common DIS PDU Set. It is supported by all the simulators except ADGESIM (the AP-3C has its own proprietary version of the Underwater Acoustic PDU) because all the other simulators considered carry out Anti-Submarine Warfare activities which is not the case for all major ADF platforms.
k) If the AP-3C simulator is to be used in ADF distributed simulation, training exercises its DIS Interface will need to be modified to be more interoperable with the other ADF simulators under consideration in this report.

6.2 Analysis of DIS PDU Traffic From Several Major Exercises

The analysis of DIS PDUs recorded during four coalition demonstration exercises carried out at HMAS Watson between the RAN and USN is shown in Table 11. However it should be noted that some PDU traffic may have been filtered out at the US end of the WAN connection between the USA and HMAS Watson. As for Table 10 the recommended, minimum basic set of DIS PDUs (discussed in section 6.3) is shown in shaded cells in Table 11.

The following can be concluded from Table 11:

a) The vast majority of the PDUs (99.25% for the Sept 03/1 exercise, 99.46% for Sept 03/2, 99.9% for Feb 03 and 97.2% for Nov 01 exercise) are contained within the recommended PDU set,
b) The major portion (approximately two thirds) of all the PDUs (64.74% for the Sept 03/1 exercise, 62.66% for Sept 03/2, 68.31% for Feb 03 and 69.60% for Nov 01 exercise) belong to the Radio Communications family (Transmit, Signal and Receive) PDUs,
c) Most of the remaining PDU traffic (27.88% for the Sept 03/1 exercise, 30.66% for Sept 03/2, 22.19% for Feb 03 and 19.57% for Nov 01 exercise) is that generated by the Entity State PDU,
d) The Fire and Detonate PDUs each account for a maximum of 0.01% of the total number of PDUs,
e) The Simulation Management family PDUs (individual PDU breakdown shown below in Table 12) on average account for approximately 0.2% of the total number of PDUs,
f) The Electromagnetic Emission PDU accounts for approximately between 2% and 8% of the total number of PDUs,
g) Similarly the IFF PDU approximately accounts for between 1% and 5% of the total number of PDUs,
h) The Underwater Acoustic (UA) PDU (which is not in the recommended PDU set because not all platforms will have/require an Underwater Warfare

capability) only accounts for a very minor part (a maximum of 0.05%) of the total number of PDUs,

i) The experimental BFTT Supplemental Electromagnetic Emission (BSEE) PDU can account for up to 3% of the total number of PDUs, and

j) The experimental BFTT Multiphase Electromagnetic Emission (BMEE) PDU can account for up to 0.5% of the total number of PDUs.

Table 11. Number of DIS PDUs for four RAN/USN Coalition Exercises (ES indicates Entity State PDU, EE indicates Electromagnetic Emission PDU, TX indicates Transmission PDU, RX indicates Receiver PDU, UA indicates Underwater Acoustics PDU, SM indicates Simulation Management PDUs, BSEE indicates Experimental BFTT Supplemental Electromagnetic Emission PDU and BMEE indicates the Experimental BFTT Multiphase Electromagnetic Emission PDU.

PDU Type	ES	FIRE	DET	SM	EE	TX	SIG	RX	IFF	UA	BSEE	BMEE	TOTAL
Sept 03/1	441,372	0	0	7,072	41,694	106,058	826,103	92,844	56,064	862	3,729	7,246	1,583,044
%	27.88%	0.00%	0.00%	0.45%	2.63%	6.70%	52.18%	5.86%	3.54%	0.05%	0.24%	0.46%	
Sept 03/2	625,509	10	10	4,343	47,577	202,598	964,020	111,490	72,591	778	3,723	7,371	2,040,020
%	30.66%	0.00%	0.00%	0.21%	2.33%	9.93%	47.26%	5.47%	3.56%	0.04%	0.18%	0.36%	
Feb 03	267718	118	106	0	98045	155452	484742	183823	16364	87			1,206,455
%	22.19%	0.01%	0.01%	0.00%	8.13%	12.89%	40.18%	15.24%	1.36%	0.01%			
Nov 01	83122	10	9	514	13291	43854	185833	65970	20321		11883		424,807
%	19.57%	0.00%	0.00%	0.12%	3.13%	10.32%	43.75%	15.53%	4.78%		2.80%		

The breakdown of the Simulation Management Family PDUs is shown in Table 12.

The following can be concluded from Table 12:

a) In the Sept 03 / 1 and Nov 01 exercises, all the Simulation Management Family PDUs were Comment PDUs. Approximately 94% (4071 out of 4343) of the Simulation Management Family PDUs from the I/ITSEC 2001 exercise were Comment PDUs.

b) In the second September 2003 CReaMS exercise (Sept 03 / 2) of the 32 participating simulation applications (32 different unique Site:Application doublets) only two of these simulation applications issued Start PDUs whereas seven simulation applications issued Acknowledge PDUs in response to all of the Start / Stop PDUs issued.

c) Similarly four different simulation applications issued a total of 14 Action Request PDUs. In response to the issuing of these Action Request PDUs six simulation applications (including the four simulation applications that issued the Action Request PDUs) issued a total of 60 Action Response PDUs.

d) Of the 32 simulation applications participating in the second September 2003 CReaMS exercise, seven had Simulation Management capabilities.

Table 12. Exercise Simulation Management Family PDU Breakdown

Simulation Management PDUs	Start	Stop	Acknowledge	Action Request	Action Response	Comment	Total
Sept 03 / 1	0	0	0	0	0	7072	7072
Sept 03 / 2	26	2	170	14	60	4071	4343
Nov 01	0	0	0	0	0	514	514

6.3 The Recommended, Basic, DIS PDU Set

The recommended, minimum, basic set of DIS PDUs that would enable a simulator to provide a sufficient level of application protocol interoperability is shown in Table 13.

Table 14 shows how the recommended, minimum, basic set of PDUs is supported in ADF simulators.

The following can be concluded from Table 14:

a) Only the RAN HMAS Watson IOTTF simulator is fully compliant with the recommended, minimum PDU set.
b) The RAN HMAS Watson CSTT Anzac ship simulator and the RAN FFG UP model only require support for the Comment PDU to be fully compliant with the recommended, minimum, basic PDU set. A simple, stand-alone, Windows simulation application, which could be easily and quickly written, could provide the required Comment PDU support for any DIS simulator.

The migration path to make the DSTO developed ADGESIM simulator fully compliant with the recommended, minimum, basic set of PDUs will be the subject of a separate report.

Table 13. The Recommended, Minimum, Basic Set of DIS PDUs

PDU Family	PDU	PDU Name	Comments
Entity Information Interaction			
	1	**Entity State**	Identification, location, behaviour, orientation and appearance are conveyed by this PDU.
	2	**Fire**	Communicates the entity that fired the weapon and the type of munition fired.
	3	**Detonation**	Conveys impact or detonation information and allows damage assessment to be made.
	4	**Collision**	Communicates information about a collision between two entities or between an entity and a terrain object.
Simulation Management			Required to control the whole simulation exercise from anywhere on the DIS network.
	13	**Start/Resume**	
	14	**Stop/Freeze**	
	15	**Acknowledge**	
	22	**Comment**	Comment PDUs can be recorded and synchronously replayed using a DIS Data Logger application.
Distributed Emission Regeneration			Required for Electronic Warfare training.
	23	**Electromagnetic Emission**	Conveys electromagnetic emission properties
	28	**IFF** **ATC** **NAVAIDS**	All military platforms of significance support IFF.
Radio Communications			Allows Radio Communications interoperability between simulators. A fundamental capability of any DIS simulator.
	25	**Transmitter**	
	26	**Signal**	
	27	**Receiver**	

Table 14. Recommended, Minimum, Basic Set PDU Support in ADF simulators (where EII = Entity Information and Interaction Family PDUs, SM = Simulation Management Family PDUs, EM = Distributed Emission Regeneration Family PDUs and RC = Radio Communications Family PDUs)

System	DIS Interface Details	EII	SM	EM	RC
RAN IOTTF (FFG)	IEEE 1278.1a	✔	✔	✔	✔
RAN CSTT (Anzac)	IEEE 1278.1a	✔	✔1)	✔	✔
RAN FFG UP	IEEE 1278.1a (Including Experimental)	✔	✔1)	✔	✔
RAN Seasprite	IEEE 1278.1a (Including Experimental)	?	?	?	?
RAAF AP-3C OMS	DIS Version 3 or 4 ? IST-CD-93-40 (7 March 1994)	✔	✔1)	✔2)	✘
RAAF ADGESIM	IEEE 1278.1a	✔3)	✘	✔	✔

1) No Comment PDU
2) No IFF PDU
3) No Collision PDU

7. DIS or HLA?

Distributed Interactive Simulation has already been described in detail in sections 3 and 4.

7.1 What Is HLA?

High Level Architecture (HLA) [33] is a methodology designed to support distributed simulation exercises. It is defined by the rules that specify how simulations interact. The HLA Run Time Infrastructure (RTI) is a programming toolkit that provides the means to exchange data during execution. HLA designates simulations as federates and a set of participating federates as a federation. Each federate has an associated Simulation Object Model (SOM) that describes its data modeling requirements, and similarly a federation has a Federation Object Model (FOM) identifying the attributes and interactions supported by the federation [11].

Federates send information via or using the HLA RTI, which in turn distributes the information to the other federates over the simulation network. For federates to be interoperable within a federation, they must all be able to subscribe and publish to the same FOM and use the same version of the same manufacturer's RTI [11]. Because RTIs are expensive this is a major problem in using HLA in a large exercise eg CReaMS.

The Real-time Platform Reference (RPR) FOM is a HLA description of the DIS PDU [34-36] structures and the data contained within those structures and has been

proposed to assist with conversion of DIS-compatible systems to HLA to promote interoperability. Federation designers can use the RPR-FOM as a starting point FOM to further develop their own FOMs for their own applications to allow interoperability between DIS and HLA applications via a DIS/HLA Gateway application.

7.2 Advanced Distributed Simulation (ADS) For The ADF

It may take as long as 10 years for a military simulator to pass through its design and development stages to be accepted into the ADF. HLA has been in development since 1996 and has had components pass through the IEEE standardisation process since September 2000 [33, 37-40]. As far as the author of this report is aware, HLA is not currently proposed or used operationally in any RAN or RAAF training simulators.

The ADF simulators described in Table 6 are all DIS simulators. The US Navy is currently fitting all its major platforms with DIS BFTT systems. The Australian Navy FFG Upgrade project will begin to bring Australian FFG ships into service with similar DIS systems by 2005 [10]. In the USAF Distributed Mission Training (DMT) program F-15 and F-16 Mission Training Centers support DIS and HLA [41-45]. The Joint Strike Fighter (JSF) simulation architecture will use HLA [46].

The ADF simulation training community is small and is mainly interested in real-time Human-In-The-Loop (HIL) training. ADF simulator applications need to be interoperable with each other and with simulation applications from Australia's coalition partners. Whereas the US DMT cockpits can interoperate using HLA (probably a RPR-FOM variant) no HLA simulators have participated in any of the three RAN - USN CReaMS training exercises carried out so far [47].

The US Simulation community is much larger and has many groups interested in many areas of simulation other than real-time training. In the USA interoperability is a major concern to almost every DoD simulation program, new and legacy. While the DIS community has evolved certain basic philosophies and tenets governing distributed simulation, HLA's architecture allows (has been designed to allow) the distributed community to be split into separate federations, each of which is free to define their own data formats and philosophies. While a given HLA federation has greater flexibility to define and control its own interfaces, the resultant diversity only complicates future efforts to interface between such federations, much less to ensure that they are truly interoperable [48].

Compared to DIS, HLA is still a developing technology. Having the DIS PDU structures, data handling algorithms (eg dead-reckoning) and data stored in those structures standardized by the IEEE has ensured a certain degree of "out-the-box" interoperability. Not knowing what data is available and how it is structured and distributed in HLA network packets has been previously described as a security feature by some in the HLA community. It is however interesting to note that the Simulation Interoperability Standards Organisation (SISO) is now proposing to

investigate the production of an Open Run-Time Infrastructure Protocol Standard which will standardize HLA RTI message formats and data handling algorithms [49] - similar to the IEEE standards that have existed since the start of DIS.

DIS standards development ceased shortly after HLA was mandated by the US Department of Defence and the USA Defense Modeling and Simulation Office's (DMSO) "No Play – No Pay" policy came into existence. It is a little known fact that training simulators were always exempted from this mandate [50].

Current (from 2000/2001) US DoD policy states [51]:

a) HLA shall be the standard technical architecture for interoperability among DoD simulations,
b) All planned upgrades or significant changes (to be defined by each DoD component) shall be HLA compliant,
c) Existing non-HLA compliant simulations intended to be interoperable shall be HLA compliant based on DoD Component requirements, resources and priorities, and
d) DoD Components shall establish their own policies and processes for transitioning their simulations to HLA or excluding them based on requirements, resources, Component priorities, or security.

It is up to each US DoD Component to establish its own HLA migration policy (including exclusion) based on requirements, resources, Component priorities, or security.

In September 2002, DMSO ceased to distribute and support (free) DMSO developed HLA RTIs and developers were instructed to purchase commercial versions of the RTI. Although HLA was originally mandated in 1996 [52-53], problems still exist. Federates typically cannot interoperate unless they are all using the same RTI implementation [54]. Performance problems in the DMSO RTIs [55] and stability problems in newer commercially available RTIs [56] have also been reported.

In 2003 SISO formed a Study Group [57] to investigate the use of DIS and HLA. Amongst the tasks of this group are:

a) Perform analysis and prepare a draft set of proposed changes to the DIS and HLA RPR-FOM Standards as well as the Enumerations that address the issues.
b) Prepare a draft set of DIS design guidelines based on the proposed changes to the standards.
c) Review the findings of the DIS Study Group for possible extension of the IEEE 1278.1 and IEEE 1278.1A standards.

7.3 Migration to HLA

Eventually HLA interoperability will (may?) be required for ADF simulators. For ADS simulators, HLA compliance can be achieved using three approaches [58-62] shown in table 15.

Table 15. Ways To Achieve HLA Compliance

Approach	Cost	Conversion Time	Speed of Operation
Gateway/Translator	Low	Short	Slowest
Middleware/Wrapper	Medium	Medium	Fast
Native	High	Long	Fastest

7.3.1 The DIS/HLA Gateway Approach

The DIS/HLA Gateway is a stand-alone simulation application (often executing on a dedicated computer) that translates network traffic between DIS and HLA (conceptual) networks [3, 59].

This approach is especially useful for legacy systems where a native HLA development process would be high risk, expensive and difficult to justify. The Gateway approach is attractive in that it is low cost, low risk, simple and quick to install and requires no modification of the legacy simulator's code [62].

A Gateway does not provide support for the full range of HLA capabilities but a legacy system is not normally endowed with these capabilities anyway. The Gateway approach may also add considerable latency. DIS/HLA Gateways will generally only support variants of the Real-time Platform Reference FOM (RPR-FOM) and, unless source code is available, a DIS/HLA Gateway may be rigidly tied to a particular FOM or a particular version of a particular FOM. If a Gateway is no longer produced or supported, using an alternate Gateway that supports the FOM required may provide an option [62].

DIS/HLA Gateways mentioned in the literature are the University Of Central Florida's Institute of Training Gateway [62] (possibly no longer available), the Naval Air Warfare Center Training Systems Division's (NAWTSD) Simulation Middleware Object Classes (SMOC) Gateway [58, 63] and the MaK Technologies DIS/HLA Gateway [64].

7.3.2 The Middleware HLA Migration Approach

The Gateway approach is a convenient, low cost, low risk option to add HLA capabilities to a legacy DIS simulator because no modification of the legacy simulator's code is required.

The middleware/wrapper approach utilises a software toolkit that encapsulates common DIS/HLA tasks into a library of pre-tested routines. This decreases the cost and risk of adding DIS or HLA to a simulation application [65]. The same library of pre-tested routines can actually support both DIS and HLA therefore allowing a simulation application to either support both DIS and HLA concurrently or to support either DIS or HLA and to then be easily modified at a later time to support the other option. Therefore a simulation application can be developed to support DIS and can be easily modified to support HLA at a later time. However simulation applications developed using the middleware approach are then tightly bound to the vendor's middleware software.

Similarly to the Gateway approach the middleware approach may not allow the simulator to take advantage of all HLA specific features.

Because the middleware approach requires software development, it is more costly, takes more time and is higher risk but will add less latency than the Gateway approach. Because the middleware toolkit manufacturer has developed and tested its software toolkit, it will be less costly, lower risk, take less development time but probably have a (slightly) greater latency than if a native HLA approach was used.

The Naval Air Warfare Center Training Systems Division's (NAWTSD) Simulation Middleware Object Classes (SMOC) toolkit [63] and the MaK Technologies VR-Link toolkit [64] are DIS/HLA middleware toolkits.

7.3.3 The Native HLA Migration Approach

The native HLA approach is the highest risk, longest development time and the most costly of the three HLA migration approaches. However once developed and debugged, the native HLA approach should add the least latency and should be able to support any HLA feature required. Supporting different FOMs may require constant and considerable software development at considerable cost. Standardizing the HLA RTI API [38] (no DIS API standard exists) will have reduced this cost and further standardizing the HLA RTI message formats and data handling algorithms [49] (similar to the IEEE standards that have existed since the start of DIS) will further reduce this cost.

7.4 DIS or HLA – A Way Forward

As shown in Table 3, current RAAF and RAN training simulators all use DIS. At SimTecT 2002 HLA compliant Army Synthetic Environment (ASE) simulators developed by the Army Simulation Office were connected to several DIS compliant systems using the MaK Technologies DIS/HLA Gateway thus demonstrating interoperability between HLA and DIS simulators [66].

A standard ADF Reference FOM has not yet been developed. A US DoD Reference FOM has also not yet been developed. The Real-time Platform Reference (RPR) FOM is a HLA description of the DIS PDU [34-36] structures has been developed to enable interoperability between DIS and HLA systems. The US Naval Training Meta-FOM (NTFM) Project [67-69] aims to provide meaningful US Navy, Marine Corps, Joint and Coalition training by achieving interoperability between US Navy training simulation systems using HLA and is based on the RPR-FOM.

Supporting different, developing FOMs may require constant and considerable software development at considerable cost. Standardising the HLA RTI API (IEEE 1516.1) [38] (no DIS API standard exists) has reduced, or is reducing, this cost and further standardising the HLA RTI message formats and data handling algorithms [49] (similar to the IEEE standards that have existed since the start of DIS) will further reduce this cost again.

In September 2002, the USA Defense Modeling and Simulation Office (DMSO) ceased to distribute and support (free) DMSO developed HLA RTIs. RTIs must now be commercially purchased.

Federates typically cannot interoperate unless they are all using the same RTI implementation [54]. RTI performance and stability problems [55-56] have been reported.

DIS standards development ceased shortly after HLA was mandated by the US DoD, DMSO's "No Play - No Pay" policy came into existence and with the release of the last DIS IEEE 1278.1A standard in 1998 until 2003 when SISO formed a Study Group [57] to prepare a draft set of proposed changes to the DIS and HLA RPR-FOM Standards for possible extension of the IEEE 1278.1 and IEEE 1278.1A standards.

In summary DIS is recommended for use in RAN and RAAF simulation applications because:

a) RAN and RAAF use of simulation is (currently) for real-time training,
b) DIS is a mature (well used and standardized) technology,
c) HLA is a developing and slowly maturing technology,
d) DIS is currently used by all major RAN and RAAF training simulators,
e) DIS has been used in all three RAN / USN CReaMS training exercises,
f) HLA has not been available for use in any CReaMS training exercises,
g) USAF DMT simulators support both DIS and HLA,
h) DIS can be used to interoperate with real USN BFTT ship systems, and
i) DIS will be able to interoperate with real RAN FFG Upgrade ship systems.

8. Conclusions

The processes used to provide a recommended, minimum, basic set of DIS PDUs for the AEW&C OMS simulator have been documented in this report.

The recommended, minimum basic set of DIS PDUs for ADF training simulators is shown in Table 13.

This basic set of DIS PDUs should provide sufficient, application protocol interoperability to enable the AEW&C OMS simulator to participate in a DIS, Wide Area Network, training exercise at the time the simulator is accepted by the Commonwealth.

All major ADF platform simulators should, as a starting point, provide support for the complete, recommended, minimum basic set of DIS PDUs.

The training functions carried out by the platform to be simulated should be analysed (a training needs analysis) and any additional PDUs required to support these functions should be added to the recommended, minimum, basic set of DIS PDUs.

Support for the recommended, minimum, basic set of DIS PDUs requires support for the latest 1998 IEEE 1278.1A version of DIS.

To support legacy DIS simulators (eg USN BFTT) ADF DIS simulators should concurrently support both DIS versions 5 and 6.

Current ADF simulators already support most of the recommended, minimum, basic set of DIS PDUs.

DIS is recommended for RAN and RAAF simulators. HLA is discounted for reasons discussed in detail in section 7.

The DSTO developed ADGESIM simulator will be migrated to the recommended, minimum, basic set of PDUs. The migration path required will be the subject of a separate follow on report [70].

To make way for HLA, DIS standards development ceased after the release of the last DIS IEEE 1278.1A standard in 1998. DIS standards development has now (2003) restarted and SISO has formed a Study Group [57] to prepare a draft set of proposed changes to the DIS and HLA RPR-FOM Standards for possible extension of the IEEE 1278.1 and IEEE 1278.1A standards. This current report could be used as an Australian contribution to a DIS Design Guide that has been proposed as one of the outputs of the new SISO DIS Working Group.

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Appendix A: Tactical Data Link (Simulation) Interoperability

In real combat, units and individuals coordinate with each other using voice and Data Links with Data Links seen as a key component in providing the necessary situation awareness to win a modern war [71].

As real Data Link information is distributed using radio communications a Data Link simulation capability was included in the DIS Radio Communications PDU family [25]. However as suitable Data Link enumeration values have only recently become available [27] each (US) service has developed its own *"proprietary"* simulated data link capabilities and many devices and protocols are required to interface all participants in a large simulation. This is compounded further by the development of new battlefield tactical data links in recent years, and the requirement for all link devices to interoperate [71].

Another way to incorporate Data Link capability in a simulation is to use messages that employ identical data, data structures and rules as the real military Data Link messages [71].

The US Department of Defense does not have any standard or minimum set of requirements to enable interoperability between Data Link simulators or Data Link simulators and real platform fielded systems. Real Data Link messages produced by simulators are *simulated real messages* and cannot be transmitted using the same medium (eg radio transmissions) and thus these simulated real messages (along with real messages) must be placed within another message (eg wrapper) when transmitted between Data Link simulators and fielded Data Link systems [71].

Various wrapper message formats can be used [71]. However the NATO Standard STANAG 5602 Standard Interface for Multiple Link Evaluation (SIMPLE) [72] is the message wrapper that has been used in US, NATO and ADF distributed simulation exercises [11, 47, 73-74]. Using real Data Link messages has the advantage of allowing a simulator to not only interface to other high-fidelity simulators but to real fielded platform systems as well. Using this method in recent RAN / USN CReaMS coalition training exercises [47, 73] enabled successful Data Link interoperability to be achieved between a RAN training simulator and a real USN Navy ship (USN Howard) [47]. Similar Data Link interoperability will be achievable between RAN (and USN) training simulators and RAN FFG Upgrade ships when the FFG ship upgrades have been completed [74].

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19. ABSTRACT

In December, 2003 the author attended the AEW&C Operational Mission System (OMS) simulator preliminary design review. The design for the Distributed Interactive Simulation (DIS) interface on this simulator was not well developed and a significant amount of work was required to bring the AEW&C OMS simulator's DIS interface up to a suitable standard to provide a useful level of interoperability. This report documents the processes used to develop a minimum, basic set of DIS message packets (Protocol Data Units (PDUs)) that should provide sufficient interoperability to enable the (or any other ADF) simulator to participate in a DIS, Wide Area Network, training exercise at the time the simulator is accepted by the ADF without expensive after acceptance modification.

Although used for the AEW&C OMS simulator the recommended, base, minimum set of DIS PDUs is not directed at any particular platform or project and is meant to be the generic starting point for any ADF simulator DIS interface. An analysis of platform specific functionality would also be required to provide additional platform specific DIS PDUs.